UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

INVESTIGATION OF THE EFFECT OF TURNOUT GEOMETRY ON THE REGISTRATION ACCURACY OF A PROPELLER-TYPE OPEN FLOWMETER

Report No. Hyd-545

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

May 28, 1965

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ABSTRACT

Measurement of the indicated discharge of a 12-in. propeller-type open flowmeter in laboratory tests showed that the deviations caused either by the change in outlet geometry or by the change in submergence of the outlet pipe did not exceed the normally specified meter accuracy of + or -2%. The meter was calibrated with the outlet pipe discharging first into an open box (unconfined outlet) and then into a confined outlet, similar to a USBR farm-turnout design. Calibrations were made for 2 water depths in each outlet type to study the effect of submergence on the indicated discharge. Over the rated range of discharges (0.45 to 4.5 cfs) the difference in indicated discharge for the 2 outlets was less than 1.7% with the maximum deviation occurring at the lowest discharge (0.45 cfs). The maximum variation in indicated discharge caused by an increase in submergence of the outlet pipe of 1.3 pipe diameters was less than 0.6% for the open box and less than 2.0% for the farm turnout. The effect of changes in submergence of the outlet on indicated discharge is not significant, as indicated by best-fit calibration curves, provided that the turnout pipe exit remains fully submerged. The farm turnout tested is probably the minimum size that should be used, because any decrease in outlet well size would cause increased turbulence in the canal section and could cause erosion of the downstream embankment.

DESCRIPTORS-- *flow meters/ turnouts/ discharge measurement/ hydraulics/ open channel flow/ hydraulic models/ model tests/ irrigation/ irrigation O&M/ water measurement/ *water metering/ water delivery/ calibrations/ meters/ outlets/ transitions/ structures// canals/ turbulence/ erosion/ submergence/ laboratory tests/ research and development

IDENTIFIERS-- propeller meters/ open flowmeters/ farm turnouts/ accuracy/ calibration curves

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Office of Chief Engineer
Division of Research
Hydraulics Branch
Special Investigations Section
Denver, Colorado
May 28, 1965

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INVESTIGATION OF THE EFFECT OF TURNOUT GEOMETRY ON THE REGISTRATION ACCURACY OF A PROPELLER-TYPE OPEN FLOWMETER

SUMMARY

The purpose of this study was to determine whether a change in the design of outlet structures for farm turnouts would affect the accuracy of discharge measurements made with an open-flow propeller meter (Figures 1 and 2). The study was carried out in conjunction with the Bureau of Reclamation water-measurement program for developing and improving water-measurement devices.

The discharge characteristics of a 12-inch propeller-type open flowmeter were studied for two outlet configurations in a full-scale laboratory model. For the initial outlet configuration, the turnout pipe discharged water into a 6-foot-wide, 6-foot-deep open box. The open box was made sufficiently large to not restrict the capacity of the outlet or have an effect on the registration of the meter. A second configuration, an outlet structure which tended to restrict the outflow but represented a practical field design, was constructed in the open box. This structure included a standard depth transition and a vertical well, the depth of which could be changed in the design as necessary to allow for the difference in elevation between the turnout pipe exit and the invert of the lateral, Figure 1B, Dimension W. Thus, a standard apron slope and warp of the transition could be used for all turnouts of the same size by varying the depth of the well. The water flowed through the outlet transition to a representative canal section, Figures 1, 2, and 3.

The discharge through the propeller meter was measured by volumetrically calibrated Venturi meters permanently installed in the laboratory. The discharge ratio, indicated propeller meter discharge to actual propeller meter discharge, was used as a measure of the accuracy of the open flowmeter in each outlet configuration. Calibration curves were determined from points plotted with the discharge ratio as the ordinate and the actual discharge as the abscissa. Meter calibration curves were

determined for two water depths in each outlet configuration to indicate the effect of submergence on the meter calibration.

The resulting calibration curves showed that, over the rated range of discharge, the differences between the discharge indicated by the meter in the open box and in the turnout configuration were less than 1.7 percent, with the maximum occurring at about 0.6 cfs (cubic foot per second), Figure 6. Also, for the rated range of discharge, the change in discharge ratio caused by submergence of the outlet pipe was a maximum of 0.6 percent at a discharge of about 1.5 cfs in the open box and a maximum of 2.0 percent at a discharge of 0.5 cfs in the farm turnout, Figures 4 and 5.

INTRODUCTION

The design of turnout transition structures for propeller meters has been similar to the transition shown in Figure 1A in which the apron slopes from the elevation of the outlet pipe invert to the invert of the lateral or canal. Because the vertical distance between the canal water surface and the invert of the outlet pipe varies for turnouts on a project and can be as much as 10 feet, the slope of the transition invert can become steeper than 1:1 causing difficulties in construction. A modified design that maintains the same transition apron slope and warped section for each turnout includes a well just downstream of the outlet pipe to compensate for the differences in elevation between the ground surface and the invert of the outlet pipe (Figure 1). Previous studies of propeller meters have been concerned with the first type of transition and this study was initiated to determine whether or not the change in turnout design affected the registration of the meter.

CALIBRATION FACILITIES

Meter

The meter used for this study was a 12-inch propeller-type open flowmeter with a 10-inch-diameter plastic propeller, Figure 2A. Prior to the calibration studies, a new propeller and matching gears were sent from the factory and installed by factory representatives. The flow of water past the propeller was indicated on a totalizer register, similar to an odometer, located in the meter head. The totalizer could be read to the nearest 0.001 acre-foot (43.56 cubic feet). The meter head contained an instantaneous flow rate indicator, similar to a speedometer needle, reading in cubic feet per second. The rated range of discharges for this meter in a 12-inch pipe is from 0.45 to 4.50 cfs.

Model

The laboratory model used for this study included a 6-foot-deep by 6-foot-wide by 8-foot-long open-top box. The inlet pipe was 12 inches in inside diameter and had a 2-foot-long transparent plastic section for visual inspection of the flow just upstream from the inlet to the open box. Figure 3 shows the laboratory model with the farm turnout and propeller meter installed. The open flowmeter was attached to the upstream headwall of the model box with two standard mounting brackets supplied with the meter, Figure 2B. Submergence of the inlet pipe was regulated by an adjustable overflow gate at the downstream end of the model and was measured with a staff gage mounted on the inlet headwall, Figure 3A.

CALIBRATION PROCEDURES

Test discharges were measured by a 4-, 6-, 8-, or 12-inch volumetrically calibrated Venturi meter known to be essentially correct. The total indicated volume of water in acre-feet passing the propeller during a measured time interval was determined from the difference between the totalizer readings at the start and at the end of the time interval. The discharge indicated by the meter was computed by dividing the total indicated volume by the time interval of the test, and converting the discharge in acre-feet per second to cubic feet per second. In general, the time required for each test was between 3 and 15 minutes and the range of indicated volumes between 0.002 acre-feet (87.12 cubic feet) and 0.10 acre-feet (4,356 cubic feet). The discharge ratio, used as a measure of the accuracy of the meter in the turnout, was computed by dividing the indicated meter discharge by the actual discharge measured by the Venturi meter. During each discharge measurement, the instantaneous flow-rate indicator was read and compared with the discharge computed from the totalizer readings.

Meter Calibration with Open Box

To serve as a standard of comparison, the initial calibration of the meter was determined for the turnout pipe discharging into the 6-foot-wide by 6-foot-deep open box. The effect of the proximity of the sidewalls and bottom of the open box on the flow passing the meter propeller was considered to be negligible. For the initial calibration, 83 tests were made for discharges ranging from 0.25 to 7.0 cfs, and a water level in the box about 2.3 feet above the top of the turnout pipe, Curve No. 1, Figure 4. To determine the effect of submergence of the outlet pipe on the calibration of the meter, 23 measurements were made for discharges ranging from 0.30 to 5.45 cfs, and a submergence of 3.6 feet in the open box, Curve No. 2, Figure 4.

Meter Calibration with Turnout Exit Structure

Following the initial calibration, a farm turnout for a 12-inch propeller meter, similar to the farm turnout design for the South Gila Valley Unit distribution system, was constructed in the model, Figures 1B and 3.

The turnout was fabricated of plywood but the vertical to 1-1/2:1 side slopes of the transition section were constructed of cement mortar.

The meter calibration for water at design depth in the downstream or canal section of the model was determined from 29 tests for discharges ranging from 0.25 to 6.52 cfs. For discharges greater than 3.5 cfs, the water surface in the outlet and in the canal downstream was extremely rough and the adjustment of the water surface was difficult, Figure 3B. The surging of the water in the exit structure could have caused fluctuations in the velocity and changes in the velocity profile of the water approaching the meter propeller. These fluctuations may have resulted in an unsteady registration of the totalizer that would not have occurred for a tranquil water surface at the same average elevation. The calibration curve for the farm turnout at design water depth is Curve No. 1, Figure 5.

To determine the effect of submergence on the calibration of the meter in the turnout, a series of tests were performed with a minimum water depth in the canal section of the model (adjustable overflow gate lowered completely). The submergence for this test series ranged from 2.2 to 3.2 feet and averaged about 1 foot lower than the submergence when the water in the canal section was at design depth. Fifty-eight tests with discharges ranging from 0.25 to 6.60 cfs were run with the minimum water depth. The calibration curve for minimum water depth in the turnout is Curve No. 2, Figure 5.

DISCUSSION OF RESULTS

The general shape of all the calibration curves is similar. A rather sharp dip or change in slope, which is typical of calibration curves for this type of meter, occurs at about 2 cfs and a sharp decrease in the discharge ratio occurs for flows less than about 1 cfs; Figures 4 and 5. For the meter installed in the open box, the effect of submergence on the discharge ratios was slight for the rated range of discharges. The calibration curves drawn as best-fit curves through the data points for each submergence indicate that the variation in discharge ratio, caused by an increase in water depth of 1.3 feet in the open box, was not greater than 0.6 percent with the maximum occurring at about 1.5 cfs, Figure 4. For the meter installed in the farm turnout, the effect of submergence on the meter calibration was also small. The maximum variation in discharge ratio, as shown by the best-fit curves through the data points for each submergence was 2.0 percent with the maximum occurring at about 0.5 cfs for the rated range of discharge, Figure 5.

The calibration curves for the meter in the open box with a submergence of 3.6 feet and for the meter in the turnout with the flow in the downstream or canal section at design depth were in good agreement, Figure 6. The depths of submergence for the two turnout exits were nearly the same and the small differences in the calibration curves were caused by either the large variance in data or the difference in outlet geometry. The maximum difference of 1.7 percent in the discharge ratios for the two calibration curves occurred at the lower end of the rated discharge range (0.45 cfs). The discharge ratios for the meter in the farm turnout are lower than for the open box for discharges below 1.5 cfs. Above 1.5 cfs, the calibration curves are very close and differ less than 0.3 percent.

Previous laboratory studies of open-flow propeller meters1/ and manufacturers' rating curves show that a sharp decrease in accuracy or discharge ratio at low discharges is characteristic of propeller-type meters; however, this decrease in accuracy usually occurs at discharges below the rated range. For this meter in the two outlets studied, a decrease in accuracy of about 5 percent occurs from 1.0 cfs down to 0.45 cfs, or within the rated discharge range. The accuracy of open-flow propeller meters of this type within the rated discharge range is normally specified at ± 2 percent and the change in accuracy of 5 percent for this meter is in excess of these accuracy limits.

The turnout exit structure shown in Figure 1A has been used on Bureau projects and has been tested thoroughly in previous studies. 1/ The change in geometry from the farm turnout design, Figure 1A, to the design studied, Figure 1B, is not as severe as a change from the open box to the farm turnout tested. Because the differences in meter calibration curves for the open box installation and the farm turnout tested are small, the differences between the calibration curves for the two farm turnouts would be even smaller. Therefore, tests on the turnout design, Figure 1A, were not included in this study.

Discharges indicated by the meter were about 7 percent higher than the actual discharge in both outlet configurations for discharges between 1.0 and 4.5 cfs. The 7 percent overregistration did not affect the determination of the changes in the meter calibration caused by changes in outlet geometry. However, the overregistration indicated by the discharge ratio is significant because the meter is to be used in a field installation where correct discharge measurements are important. The instantaneous flow indicator read 0.30 cfs higher than the discharge computed from the totalizer for the full range of discharges.

CONCLUSIONS

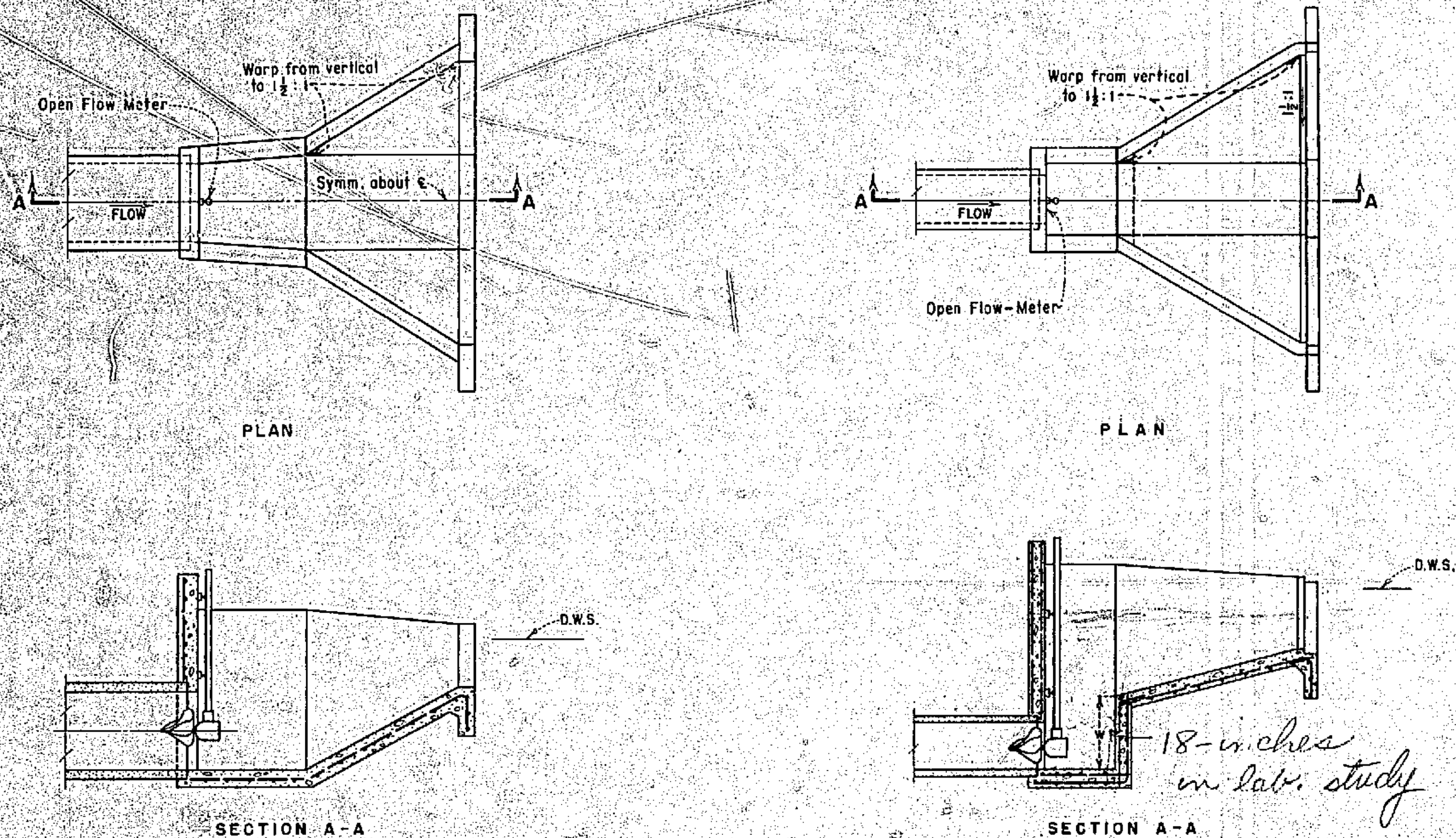
1. The effect of changes in submergence of the outlet on the indicated discharge of this propeller-type open flowmeter is not significant, as indicated by best-fit calibration curves, provided that the exit of the turnout pipe remains fully submerged, Figures 4 and 5.

1/Hydraulic Laboratory Report No. Hyd-478, "Study of the Effects of Turnout Design on the Registration Accuracy of Propeller Meters Placed in Downstream Ends of Turnout Pipes," U.S. Bureau of Reclamation, April 1961.

2. The change in the indicated discharge of the meter, caused by the change from an open box to the farm turnout design, was not greater than 1.7 percent for the rated range of discharges based on best-fit calibration curves through the data for each exit configuration, Figure 6.

3. Surging of the water surface in the farm turnout tested for discharges greater than 3.5 cfs may have resulted in unsteady registration of the totalizer. The farm turnout tested is probably the minimum size that should be used because any decrease in the size of the outlet well would cause increased turbulence in the canal section and could cause erosion of the downstream embankment.

4. A consistent 7 percent overregistration of the meter did not affect the purpose of this study; however, for a field installation of this meter, the meter readings should be corrected to determine accurate discharges.

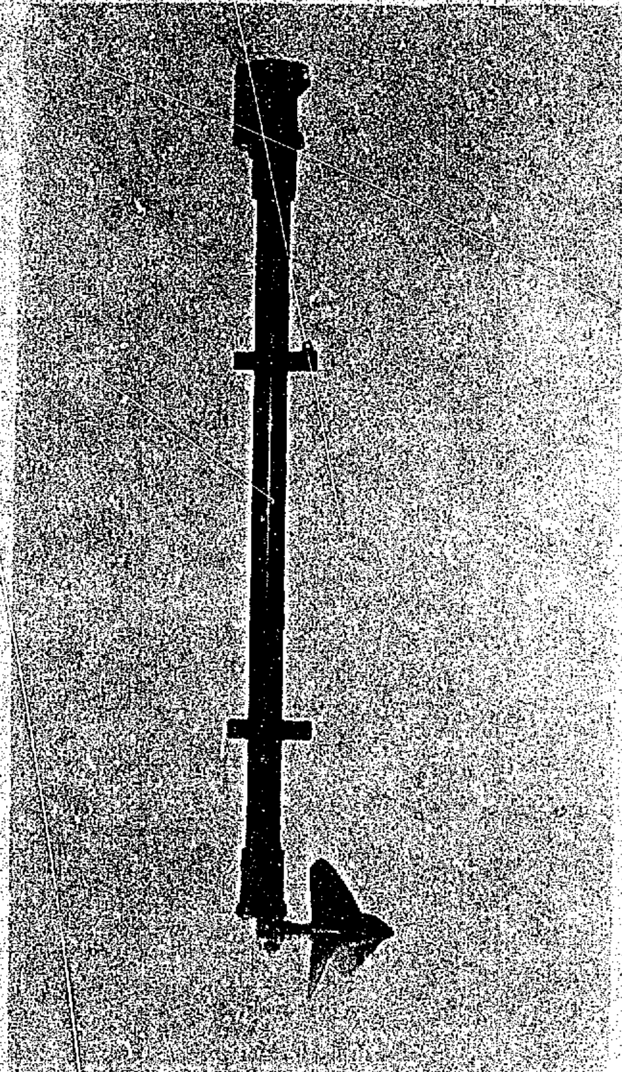


A. TURNOUT STRUCTURE – PREVIOUS STUDIES

B. TURNOUT STRUCTURE CHANGE

OPEN FLOW METER TURNOUTS

FARM TURNOUT STRUCTURES



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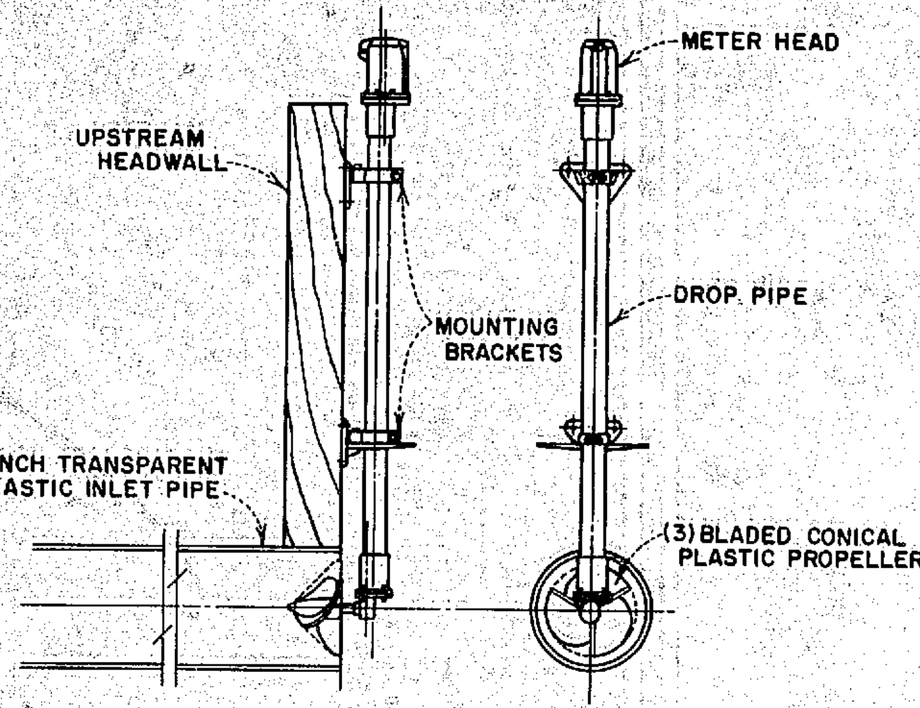
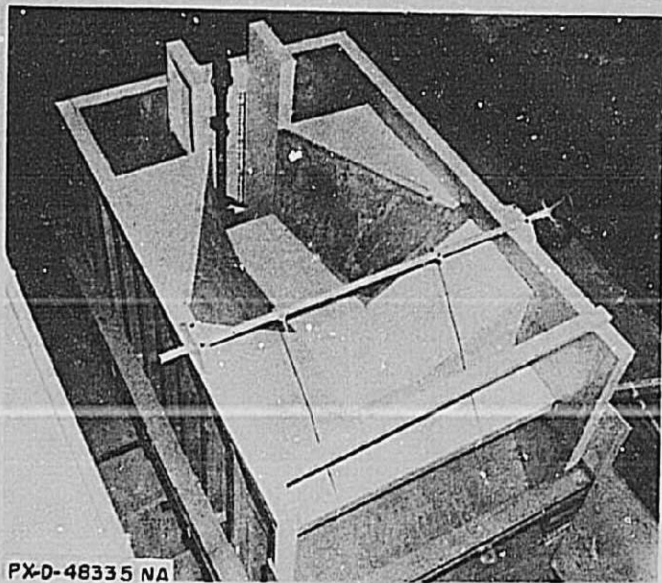
A. 12-INCH OPEN FLOW PROPELLER METER



B. METER INSTALLATION IN LABORATORY MODEL

OPEN FLOW METER TURNOUTS

OPEN FLOW PROPELLER METER AND INSTALLATION



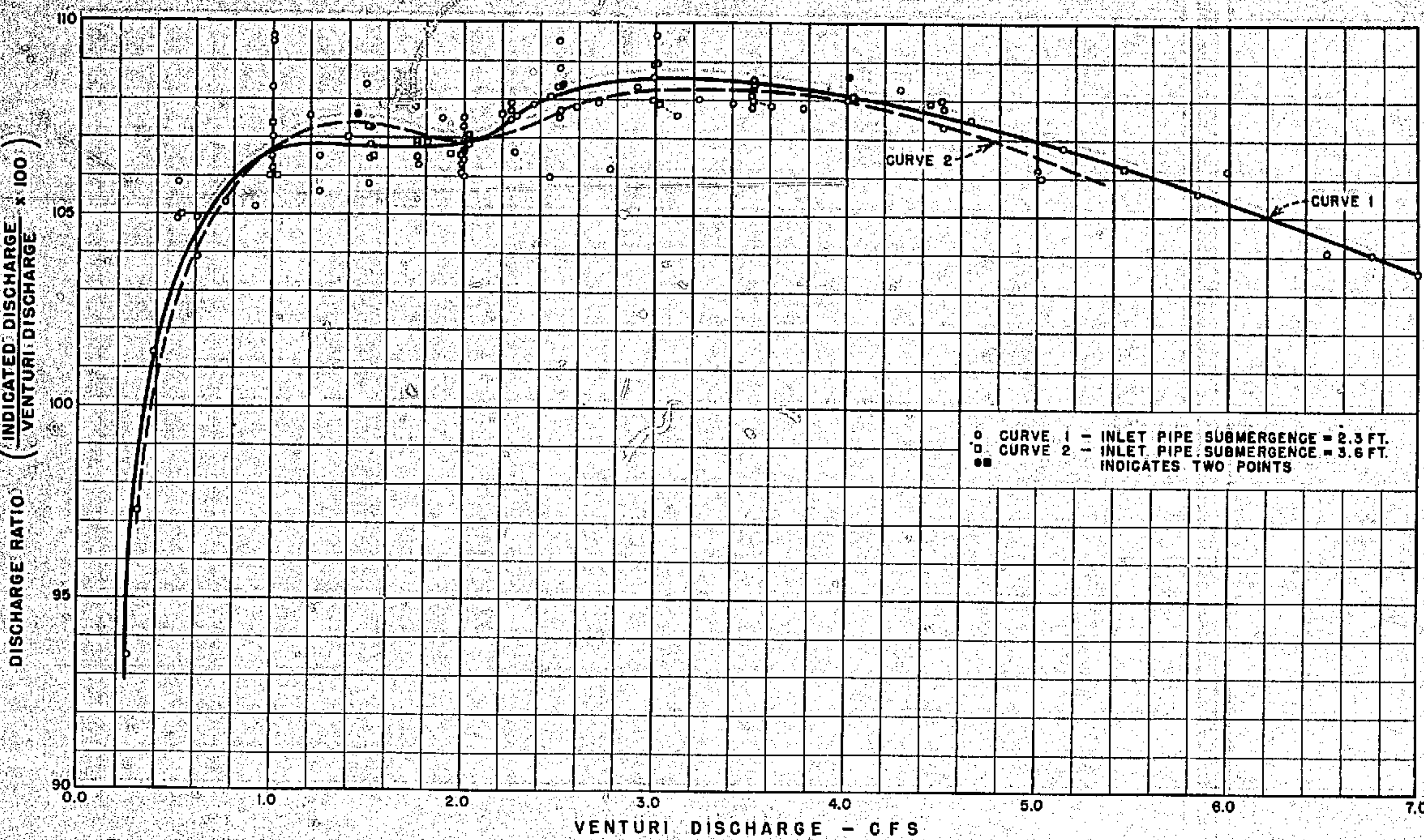
A. Laboratory model of farm turnout with propeller meter installed.

B. Farm turnout model with water at design depth, Discharge = 5.0 cubic feet per second.

OPEN FLOW METER TURNOUTS

LABORATORY MODEL OF FARM TURNOUT
FOR OPEN FLOW PROPELLER METER

FIGURE 4
REPORT HYD. 545



OPEN FLOW METER TURNOUTS

METER CALIBRATION CURVES - OPEN BOX INSTALLATION

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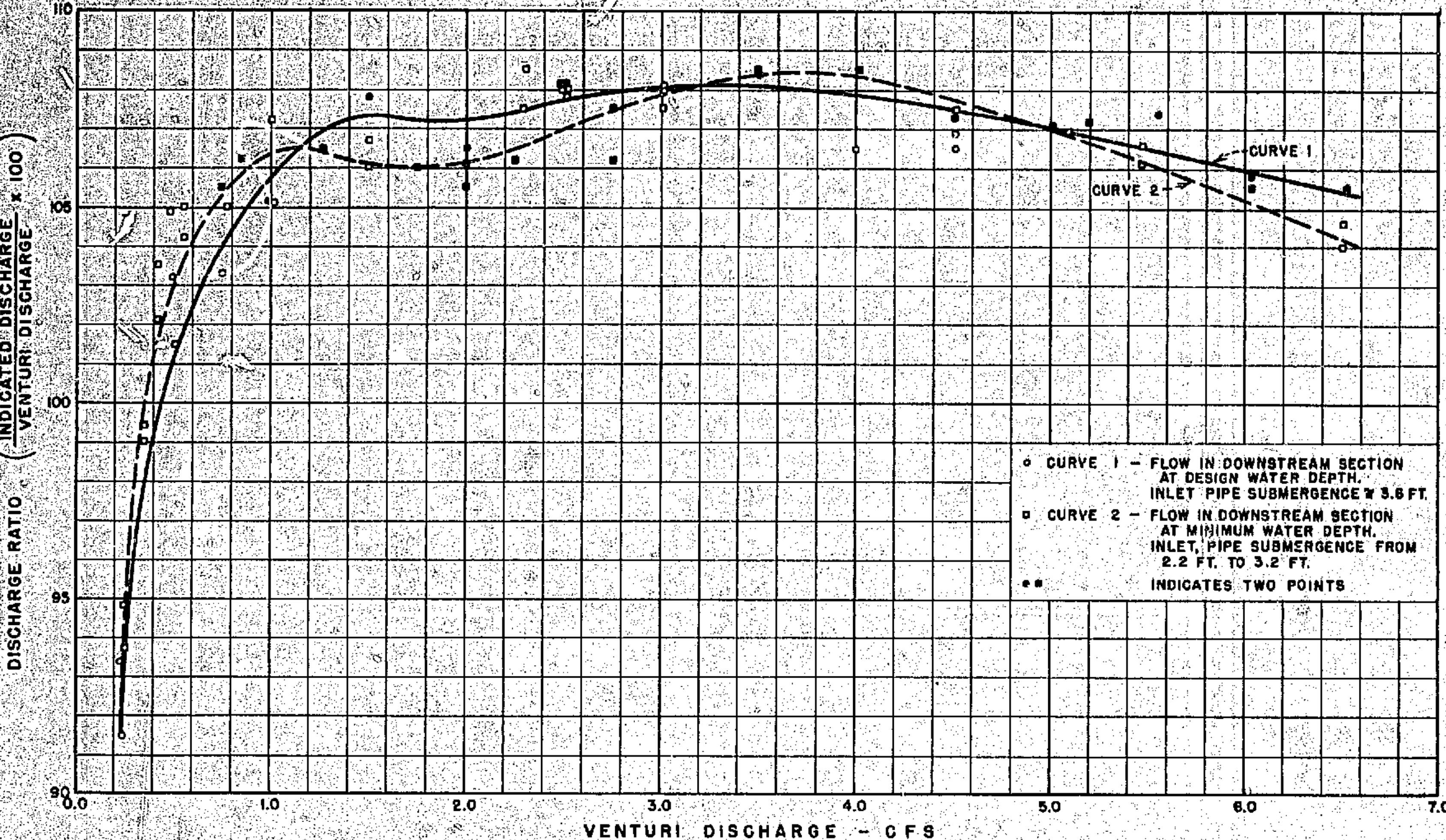

OPEN FLOW METER TURNOUTS

METER CALIBRATION CURVES - FARM TURNOUT INSTALLATION

B Fig 1

FIGURE 5
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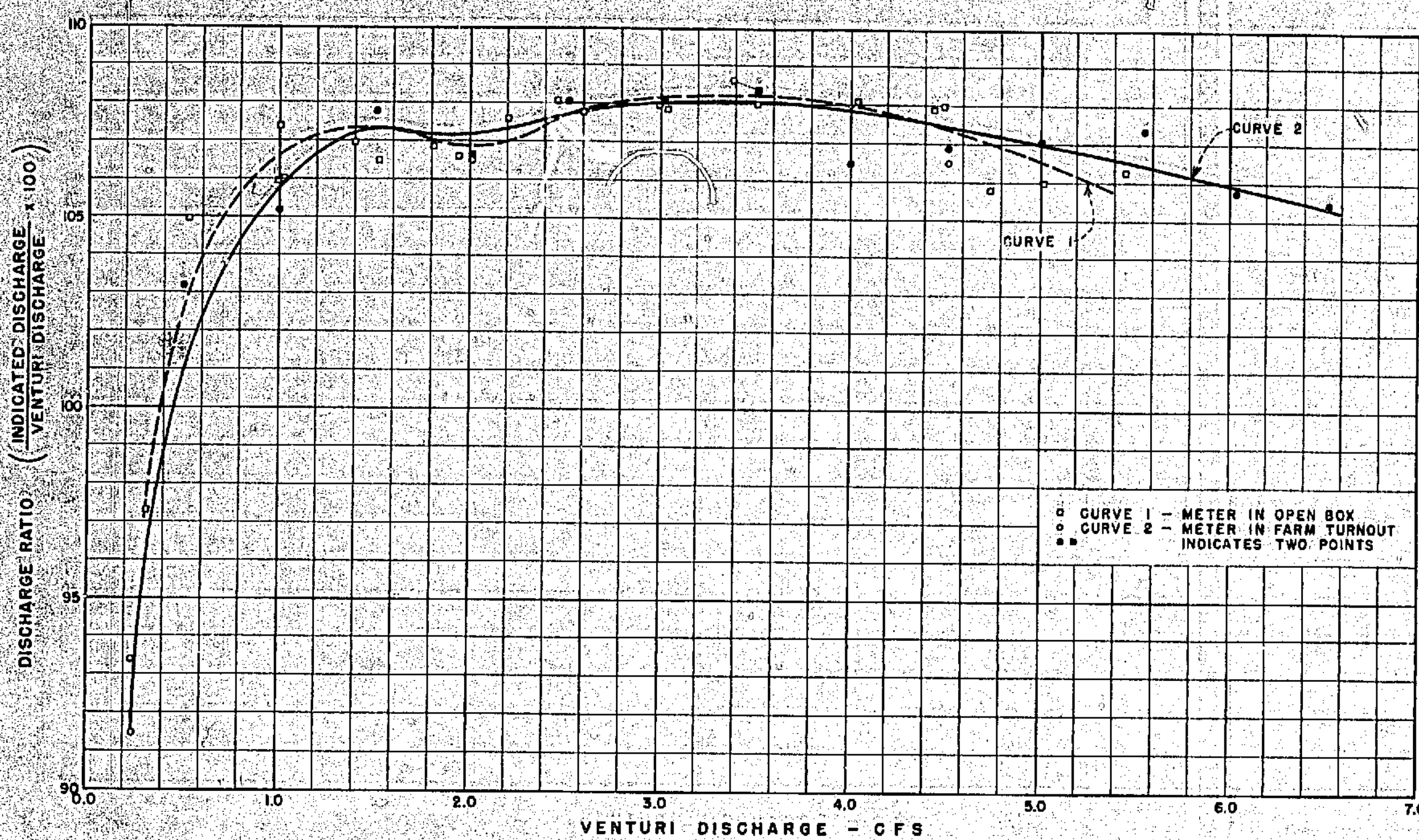

OPEN FLOW METER TURNOUTS

METER CALIBRATION CURVES - OPEN BOX AND FARM TURNOUT

GPO 850-636

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 845-237

ABSTRACT

Measurement of the indicated discharge of a 12-in. propeller-type open flowmeter in laboratory tests showed that the deviations caused either by the change in outlet geometry or by the change in submergence of the outlet pipe did not exceed the normally specified meter accuracy of + or -2%. The meter was calibrated with the outlet pipe discharging first into an open box (unconfined outlet) and then into a confined outlet, similar to a USBR farm-turnout design. Calibrations were made for 2 water depths in each outlet type to study the effect of submergence on the indicated discharge. Over the rated range of discharges (0.45 to 4.5 cfs) the difference in indicated discharge for the 2 outlets was less than 1.7% with the maximum deviation occurring at the lowest discharge (0.45 cfs). The maximum variation in indicated discharge caused by an increase in submergence of the outlet pipe of 1.3 pipe diameters was less than 0.6% for the open box and less than 2.0% for the farm turnout. The effect of changes in submergence of the outlet on indicated discharge is not significant, as indicated by best-fit calibration curves, provided that the turnout pipe exit remains fully submerged. The farm turnout tested is probably the minimum size that should be used, because any decrease in outlet well size would cause increased turbulence in the canal section and could cause erosion of the downstream embankment.

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Bureau of Reclamation, Denver, 6p, 6 fig, 1965

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INVESTIGATION OF THE EFFECT OF TURNOUT GEOMETRY ON THE REGISTRATION ACCURACY OF A PROPELLER-TYPE OPEN-FLOW METER
Bureau of Reclamation, Denver, 6p, 6 fig, 1965

DESCRIPTORS-- *flow meters/ turnouts/ discharge measurement/ hydraulics/ open channel flow/ hydraulic models/ model tests/ irrigation/ irrigation O&M/ water measurement/ *water metering/ water delivery/ calibrations/ meters/ outlets/ transitions/ structures// canals/ turbulence/ erosion/ submergence/ laboratory tests/ research and development
IDENTIFIERS-- propeller meters/ open flowmeters/ farm turnouts/ accuracy/ calibration curves